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Calibration of the Cole-Flad Pitometer

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CALIBRATION

OF THE

COLE-FLAD PITOMETER

BY

GEORGE LOYAL SAWYER

THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

MUNICIPAL AND SANITARY ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

PRESENTED JUNE 1903

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June 1, 1903 190

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

GEORGE LOYAL SAWYER

ENTITLED CALIBRATION OF THE COLE-FLAD PITOMETER

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Municipal and Sanitary Engineering.

A. N. Talbot

HEAD OF DEPARTMENT OF Municipal and Sanitary Engineering

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The Calibration of the Cole-Flad Pitometer

For some years it has been realized by engineers and others interested in water works that a great deal of the water pumped for large cities is wasted. In order to detect this waste, and also to measure the amount of water flowing through any main, several instruments have been devised. One of the most successful of these devices was invented in 1896 by Mr. Edward V. Cole of Chicago, Illinois and Mr. Henry Flad of St. Louis, Missouri. The instrument was devised in order to furnish an economical method of measuring the flow of water in pipes. While the Venturi, and the disc meters give accurate results, yet they would not be practicable in many kinds of water survey.

It was found necessary in 1896

to adopt some means of determining the amount of water flowing through the water mains of Terre Haute, Indiana, and the pitometer, as used in this water survey, proved to be very efficient, as well as cheap and accurate. In 1912 it was used in a similar survey of the city of Columbus, Ohio, and there again it showed its value. At the present time it is being used in a survey of the water mains of New York City, N. Y. The Borough of Manhattan, in which the survey is being carried on, has a daily consumption of 1.5 gallons per capita. This is certainly in excess of the water properly used by the patrons of the water system, and the water commissioners desire to find where, and how much the actual waste is. In carrying on this survey the city is dividing into districts of such size and boundaries

as will allow the entire flow to to pass though one or two mains. The mains are then tapped and the pitometers are inserted. The amount of water passing though the main can thus be determined. This district is practically all metered so that the flow, as determined by the pitometer, minus the total metered flow, would give the quantity of water wasted by leakage or otherwise. The results thus far obtained have been most satisfactory. At the present time Mr. Cole is conducting a similar survey in Brooklyn, and is obtaining very satisfactory results.

The pitometer can best be described from the drawing (Fig. 1). The instrument does not record quantities directly, but it shows the velocity from which the quantity can be obtained. As stated in the previous paragraph, the main is tapped

FIGURE 1

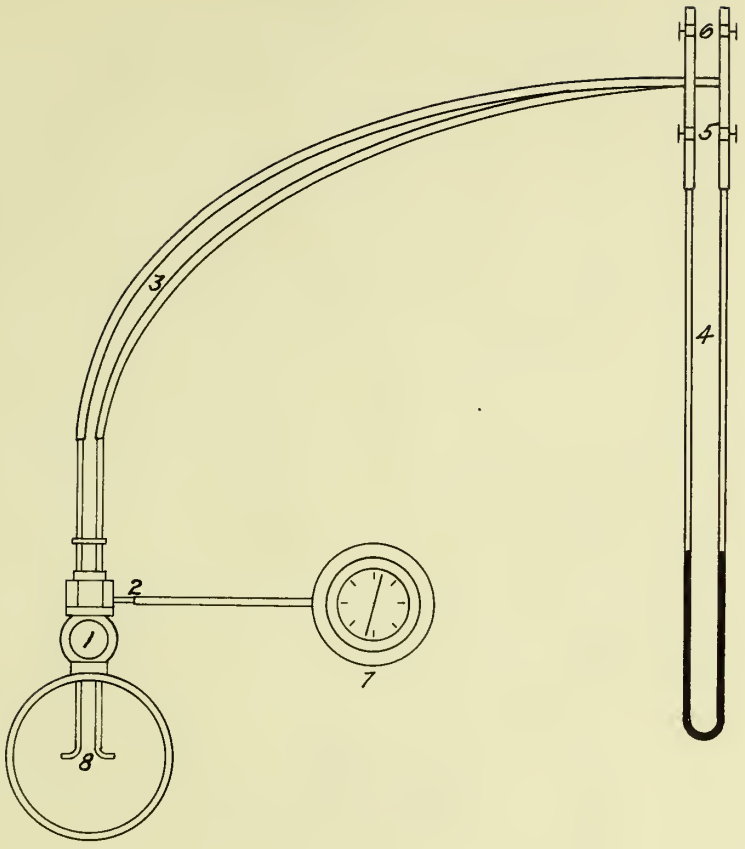
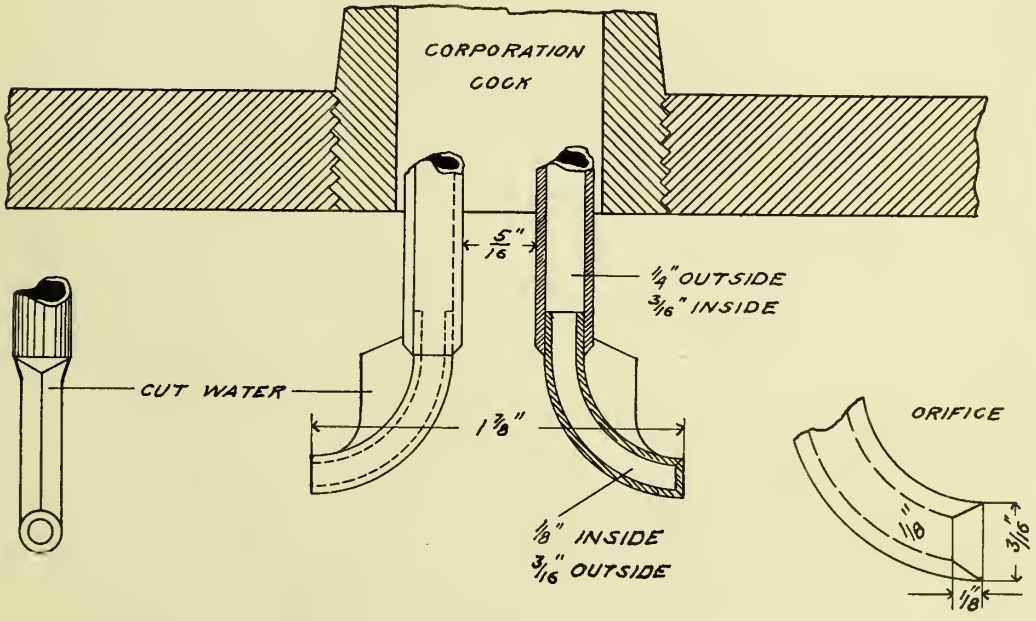


FIGURE 2



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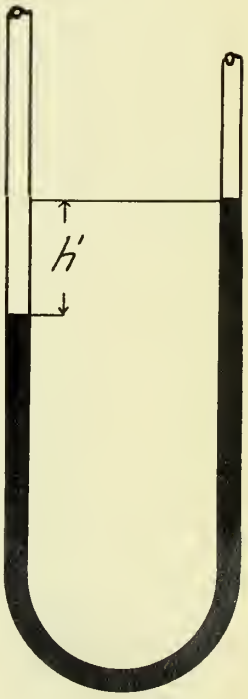
by the ordinary method at the point where the velocity is desired, and a corporation cock (1), of special design, is inserted. The only peculiar feature of this corporation cock is that the cap is so arranged that the two pitot tubes (8) can be passed through. From the side of the corporation cock a short tube (2) leads to the air. This may be connected to a pressure gauge (7) so that the water pressures can be read at the same time the deflections are being recorded. The pitot tubes and corporation cock are shown in section in figure 2. The pitot tubes are carefully made, having an internal diameter of 1/8 in. and connected to 1/4 in. tubes. The curved portion of the pitot tube is provided with cut water edges so that the velocity will not be reduced by contact with the tube. Various sizes of orifices have been

experimented with but the dimensions as given on the previous page were found to produce the most accurate and satisfactory results. From the pitot tubes are run two lines of 1/4 in. cloth insertion rubber tubing (3 Fig. 1). This tubing is pasted tightly to the pitot tubes by means of wire and also to the U tube (4), as it is absolutely necessary that no air get into any of the connections. This rubber tubing is provided with stop cocks (5 and 6) by means of which the air may be released. The U tube (4) is a glass tube of the ordinary type being 27 inches long and having an internal diameter of 5/16 in. This U tube is filled about one half full with a mixture of carbon tetrachloride and gasoline, having a specific gravity of 1.35 to 1.50 depending upon the velocity to be measured. This mixture is colorless but shows a distinct line when it comes in

contact with the water. In case of high velocities it is best, if not absolutely necessary, to use a liquid of higher specific gravity, as there is a tendency for the water to filter past the mixture. In order that a continuous record of deflections may be kept, a photographing device has been arranged. By this method one leg of the U tube is exposed to the velocity pressure and by means of a small shutter the deflections are photographed upon the paper. The instrument in itself is simple, accurate, efficient, and inexpensive.

The purpose of the pitometer is to measure the velocity head of the flowing water. If the instrument measured the amount of the actual velocity head at a point in the pipe, the velocity would be determined by the formula $h = \frac{v^2}{2g}$ in which h = the

velocity head, v equals velocity of the water, and g equals the acceleration of gravity, or transposing $v^2 = 2gh$. Since the pitometer does not record the exact velocity head, the formula becomes $v^2 = c^2 2gh$, when c is the ratio of the velocity indicated by the water column to the actual velocity. Since a liquid heavier than water is used, it is necessary to find what head of water is equivalent to the pressure shown by the liquid. Let h', in the figure to the right, equal the difference in level of the liquid in the two legs of the U tube, and h equal the head of water equivalent to the differential effect of the two liquids, and x equal the specific gravity of the liquid in the bottom of the U tube. Then $h = h'x - h' = h'(x-1)$. As-



suming that $x = .75$, $h = \frac{h'}{4}$ or the differential effect in the U tube is equivalent to four times the simple water head. Substituting the value of h in the formula $v' = c\sqrt{2gh}$, the equation becomes $v' = c\sqrt{2gh'(x-1)}$ or, solving for c, $c = \frac{v'}{\sqrt{2g(x-1)h'}}$.

In the calibration tests, mentioned by Mr. Cole, various velocities were used. In some tests made at Terre Haute, Indiana, he used a series of cast iron water pipes, placed end to end and provided with a supply of water from a reservoir giving a constant pressure of approximately 10 lbs. per sq. in. These pipes varied in size from 6 inches at the upper and lower ends to 12 inches in the middle. Pitometers were placed in each size of pipe. The water was measured by means of a carefully calibrated weir placed at the lower end of the line of pipes. At the Twenty Second street pump-

ing station in Chicago Mr. Cole has recently conducted some calibration tests. In this case he used a 4-inch semi-circular trough made of galvanized iron. The pitometers were tapped in through the bottom. For determining the velocities in these tests he used floats and a stop watch. At Petoskey Michigan Mr. Cole used a rectangular channel 24 inches wide. The results of these calibration tests by different methods checked very closely.

After considering the various methods already used, and others that might be adopted, it was decided to use a scheme somewhat similar to that used by Mr. Cole in Chicago. This method seemed to be more representative of actual conditions than any other. In place of a galvanized ~~wrought~~ iron trough a length of 8-inch wrought iron pipe was cut longitudinally through the en-

ter, and the ends so joined together as to make a 40 ft. semi-circular channel. The apparatus was arranged as shown in figure 3, plate 7. The water was supplied from a 60 ft. stand pipe 4 ft. in diameter. With the low velocities the capacity of the stand pipe was sufficient to furnish water for the tank (a) throughout an experiment, but with high velocities it was also necessary to pump continually into the stand pipe. At times water was supplied directly from the University water mains. The water was discharged into the tank (a) from the 6 inch pipe (b). At the end of the tank was placed an adjustable overflow (c). This could be revolved about the joint (c), so that any desirable head might be obtained. This overflow however was not used as the head could be controlled by the valve on the supply pipe (b). With high velocities it was necessary to reduce the disturb-

FIGURE 3

ARRANGEMENT OF APPARATUS

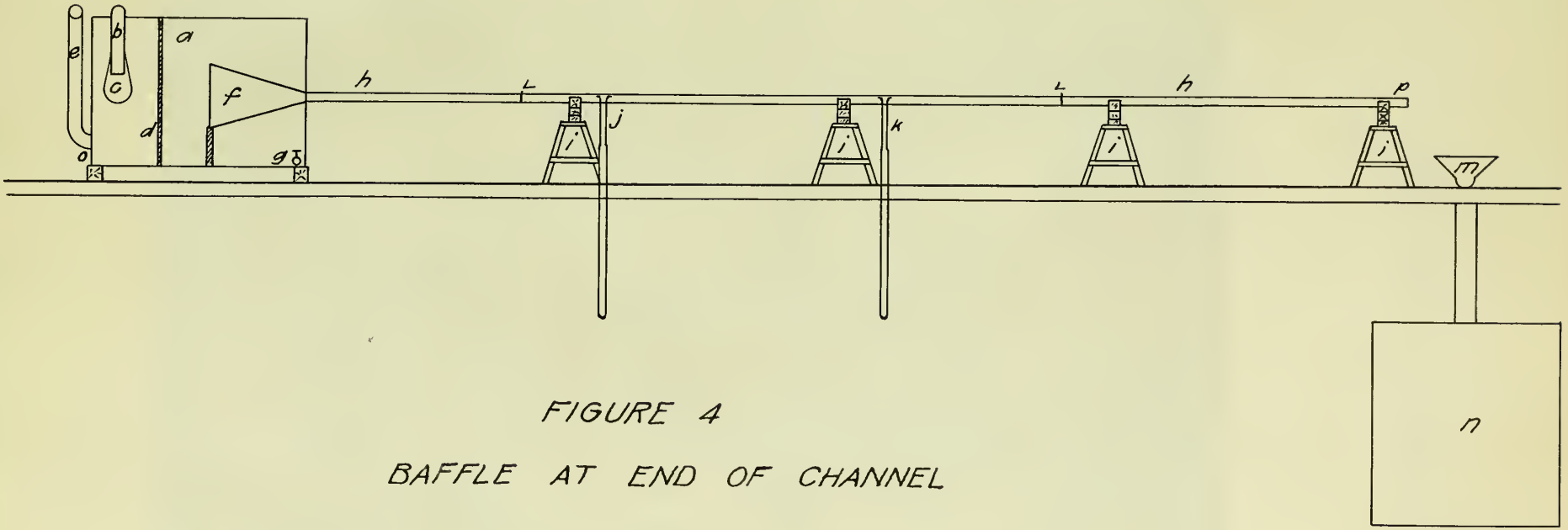


FIGURE 4

BAFFLE AT END OF CHANNEL

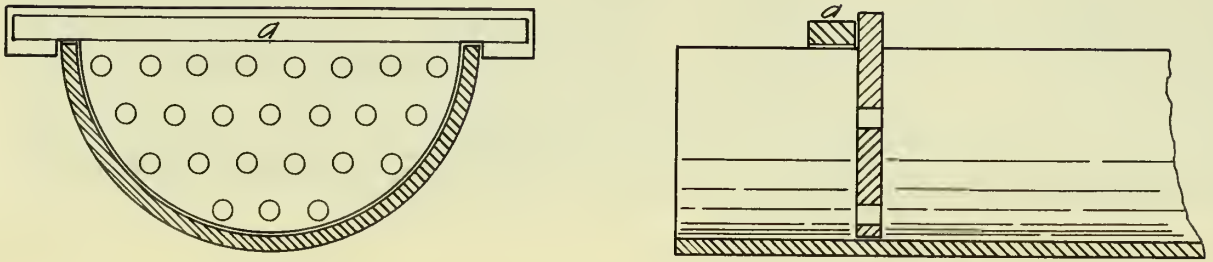


PLATE 2

10a

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END VIEW OF APPARATUS

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SIDE VIEW OF APPARATUS

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SIDE VIEW OF APPARATUS

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VIEW OF PITOMETER (K)

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made caused in the water by the flow from the supply pipe. This was accomplished by tying around the mouth of the supply pipe a gunny-sack (c) and placing immediately in front of it a baffle board (d), a board of boards placed close together and perforated every few inches. To overcome the contraction of the section at the entrance to the channel, and the resulting wave action, a funnel 3'2 ft. in diameter at one end and 7½ inches at the other, having a length of about 1'2 ft., was placed in the orifice and braced as shown in the diagram. A water tight joint was made between the funnel and the channel proper. Chicago A-A Cement. By this means a gradual reduction of section was produced from the basin to the channel, and the wave action entirely eliminated. The tank was supported at the ends

on 6 x 6 inch timbers, so that it could be more easily tilted, when the higher velocities were desired. The channel (H) was supported at the middle, quarter points, and the ends, at the upper end it was resting on the bank and at the other points it was supported on horses, so that the level of its invert was about 3 feet above the floor. A 20-ft. course (L) was marked off on the channel, beginning about 5 ft. from the upper end. It was over this course that the time of the floats was observed. The tap for the piezometer (I) was 3 ft. below the upper end of the 20 ft. course, and that for the gauge (K) was 6½ ft. above the lower end of the course. The piezometer with about ¼ in. of rubber tubing was allowed to hang over the edge of an opening in the floor, so that the difficulty of removing the air from the instrument was

reduced. About 4 inches from the lower end of the channel was placed a baffle (p). This is shown in detail in figure 4 plate 2. The purpose of the baffle was to keep the flow at the end of the channel as nearly at the same depth as at all other points in the channel. It was made of 1/2 inch pine having perforations every inch horizontally and vertically. It hung upon the edges of the channel so that it was free to swing. The size of opening under the baffle was adjusted by moving the 1 x 2 inch cast iron bar (a) either toward or away from the end of the channel. With the lowest velocities (.4 ft. per sec.) the opening at the bottom was almost reduced to zero, while with the higher ones (3.0 ft. per sec. and above) the baffle was entirely removed. This method gave a very easy but [illegible] means of regulating the velocity and

depth of flow at the end of the channel. The water was received from the end of the channel by a funnel (m). The funnel transferred the water to a circular concrete tank (n) on the first floor, from which a channel led to a sump. From this sump the water was again pumped to the storage pipe.

Each experiment may be divided into 3 parts as follows; (1) the reading of the floats, (2) the reading of deflections, and (3) the determination of the specific gravity of the liquid. The floats used were cork cylinders 3/4 x 1/2 in. diameter with the edges rounded off to reduce the friction of the water as much as possible. Other floats of various sizes and shapes were tried but these produced the most satisfactory results. The float was loaded at one end by means of small nails, so that the upper

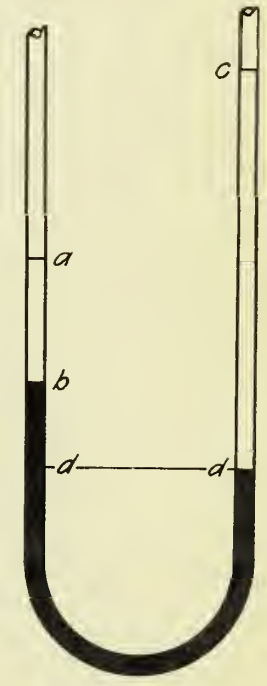
end of the float was at the same level as the surface of the water. The float was then started 4 or 5 ft. above the 70-ft. course and caught by the stop watch as it passed the starting point. If it kept in the center of the channel the time at the end of the 70-ft. course was recorded. As many as 20 or 30 readings were taken at times, to make sure that the velocity obtained was that at the center of the channel. With such velocities as 5 ft. per. sec. and higher it was difficult to obtain very accurate time with the stop watch. Two schemes for the use of the chronometer were considered, but proved impracticable. The first was to have a contact wire on the float, which should touch wires at the upper and lower ends of the 70 ft. course. There was not much doubt that the time lost

in making the contact would produce a greater error than would the stop watch. The second plan was to place a narrow slit at each end of the course, and press a key as the float was observed to pass under the slit. Here would enter the same error as was produced in the use of the stop watch; that was that the eye was not quick enough. While it was difficult to read the stop watch to 1/10 of a second yet it was done without great error.

As soon as a constant plan was obtained and the velocity with the floats was determined, the deflection in the U tube was read. A piece of heavy white cardboard, graduated to inches and tenths of inches, was placed behind the U tube from which the deflections could be taken. For all velocities above 7 or 3 ft. per sec. it

was almost impossible to bring the liquid to a state of rest. Before taking any experiments the end of the channel was dammed up and then filled with water. With this condition of zero velocity the liquid was brought to the same level in both legs of the U tube by removing the air. This was accomplished by opening the cocks at the top of the rubber tubing (6, fig. 1, plate 1), so that whatever air was present could escape either through the pitot tubes or these cocks. It was necessary to tap the instrument with the fingers a number of times to remove the air, as it had a tendency to catch at all joints and corners. In the case of high velocities, where it was difficult to dam up the channel, and then remove the dam before the water could run out of the channel, thus allowing air to enter the pitot tubes,

the liquid could be brought to the same level in both legs by turning the petal tubes normal to the current. This would give no velocity through the tubes so that the air could be removed as previously described. The tubes were turned, one toward the upstream and the other toward the down stream and then read. In reading the deflections the mean was taken and not the maximum vibrations of the liquids.



Before and after each 3 or 4 hours work, the specific gravity was determined as follows: (See figure on the right) Let the U tube be filled with the mixture to the points b and d. Above this is water to the points a and c. Since there is equili-

brium the weight of the water cd must be equal to the weight of the water and liquid ad. or $cd = ab + bdx$ where x is the specific gravity of the mixture. $x = \frac{cd - ab}{bd}$. As an example take the following. $cd = 6.31$ in., $ab = 4.86$ in. and $bd = 1.17$ in. $x = \frac{6.31 - 4.86}{1.17} = 1.29$. It was found that the specific gravity would not vary enough in 6 hours to affect the results but that in 2 or 3 days it would increase as much as .01. The reason for an increase in specific gravity is that the gasoline in the mixture evaporates and since it has a specific gravity of from .60 to .50 and carbon tetrachloride of 1.63, evaporation of the gasoline will give a proportional increase in the specific gravity of the mixture.

The chief difficulty encountered in the calibration tests was the removal of air from the pyrometer. Each water and mercury

nished a corner in which [illegible] less air could collect. This resulted in a deflection in the U tube even when there was no velocity in the channel. The method of removing the air has already been described. It seems simpler than it really was, for with the low velocities especially, the air seemed to work back and forth from corner to corner. With the higher velocities it was not necessary to exercise such great care, as the U tube deflections could not be read so closely. Here however there was not much trouble with the air, as the greater pressures were easily forced it out.

The pitot tubes were placed 3/4 in. below the surface of the water for the low velocities, as this would give deflections due to the velocity at the middle of the float. This same distance should have

been observed with the higher velocities, but, when the pitot tubes were placed that close to the surface, considerable air was drawn into the tubes, due to a breaking of the current at the orifice. With the lower velocities the cut water edges disposed of this trouble.

As the velocities were raised above 4 ft. per sec. it was found that the water was passing by the mixture of carbon tetrachloride and gasoline, due to the fact that the specific gravity of the liquid was too near that of the water. To overcome this a solution of normal carbon tetrachloride was substituted for the mixture, and the desired effect was produced.

Considerable trouble was encountered at first in getting the desired slope to the channel. The method finally adopted was to set the lower end of the channel at a

bout the desired elevation by means of a jack. Then by means of a string, or simply sounding with a short stick, the pipe was given a uniform slope. If then the velocity was not just what was desired the pipe was raised or lowered, till the right velocity was obtained, and an uniform depth prevailed at all points.

As previously shown $c = \frac{V}{8.02\sqrt{h'(x-1)}}$, where c equals the coefficient, V equals the velocity in ft. per sec., h' equals the U tube deflection in ft. and x equals the specific gravity of the liquid at the time the reading was taken. The method of calculation may be illustrated by the following example: From the table the following data are obtained; the velocity, as determined by floats, .40 ft. per sec.; the U tube deflection, .15 in.; the specific gravity, 1.31. Since the velocity is in ft. per sec. the deflection

h' must be expressed in ft. $h = .10$ ft., $= .0125$ ft. $x - 1 = 1.31 - 1.00 = .31$ $\sqrt{h'(x-1)} = \sqrt{.00387.5}$

$C = \frac{.40}{.03 \times .0622} = .40$

As the table shows the coefficient of velocity, C, was in no case less than .75, nor more than .82. The average of the coefficients was .810. This may be considered the coefficient of the instrument and the values agree very closely with .80, the value used by Mr. Cole.

Having determined the coefficient ($C = .802$), the discharge may be found from the formula $q = CAV$, in which q equals the quantity discharged in cu. ft. per sec., C equals the coefficient of velocity, A equals the area of the cross section and V equals the velocity in ft. per sec. This quantity must be multiplied by the ratio of the average velocity to the velocity taken.

The results of the calibration tests show that the pitometer is an

accurate instrument, if properly and carefully manipulated. Great care must be taken in the removal of air, in the determination of the specific gravity, in placing the pitot tubes at the center of the flow, and determining the relation of the velocity at the center to the average velocity in the pipe. If these points are carefully watched results should be obtained to within 1 - 2 per cent. The pitometer is doubtless as economical an instrument as there is at present on the market. It is not expensive to construct, or to install, and the cost of operation is low. Although this instrument has been used almost exclusively on water main surveys, it is useful in determining the slip of pumps, and the flow of water in streams where the cross section is not too variable. The reason that the Cole-Flad pitometer has not

yet been used extensively is that engineers are not aware that this simple, economical and accurate method of measuring the flow of water through pipes is available.

CALIBRATION OF THE COLE-FLAD PITOMETER
RESULTS OF EXPERIMENTS

TIME PER 20 Ft. SECONDS	VELOCITY V FT. PER SEC.	U-TUBE DEFLECTIONS INCHES	SPEC. GRAVITY X	COEFFICIENT C
50	40	.15	1.31	.80
49	39	.15	"	.80
49	41	.16	"	.80
50	40	.16	"	.78
49	41	.16	"	.80
49	41	.16	"	.80
24 3/5	81	.63	1.31	.78
24 2/5	82	.62	"	.81
24 2/5	82	.62	"	.81
24 1/5	83	.63	"	.80
24 3/5	81	.62	"	.81
15	1.33	1.74	1.30	.80
14 4/5	1.35	1.70	"	.81
14 4/5	1.35	1.74	"	.81
15 1/5	1.32	1.72	"	.80
14 4/5	1.35	1.74	"	.81
6 2/5	3.15	10.00	1.29	.80
6 1/5	3.20	10.15	"	.81
6	3.25	10.20	"	.81
6	3.25	10.10	"	.80
6 2/5	3.15	10.20	"	.79
6 1/5	3.20	10.15	"	.81
5	4.00	7.55	1.63	.80
4 4/5	4.08	7.70	"	.80
4 3/5	4.17	7.70	"	.82
5	4.00	7.60	"	.80
5	4.00	7.55	"	.80
3 4/5	5.26	13.00	1.63	.80
3 3/5	5.41	13.00	"	.82
3 4/5	5.26	12.80	"	.80
3 4/5	5.26	12.75	"	.81
3 4/5	5.26	13.00	"	.80

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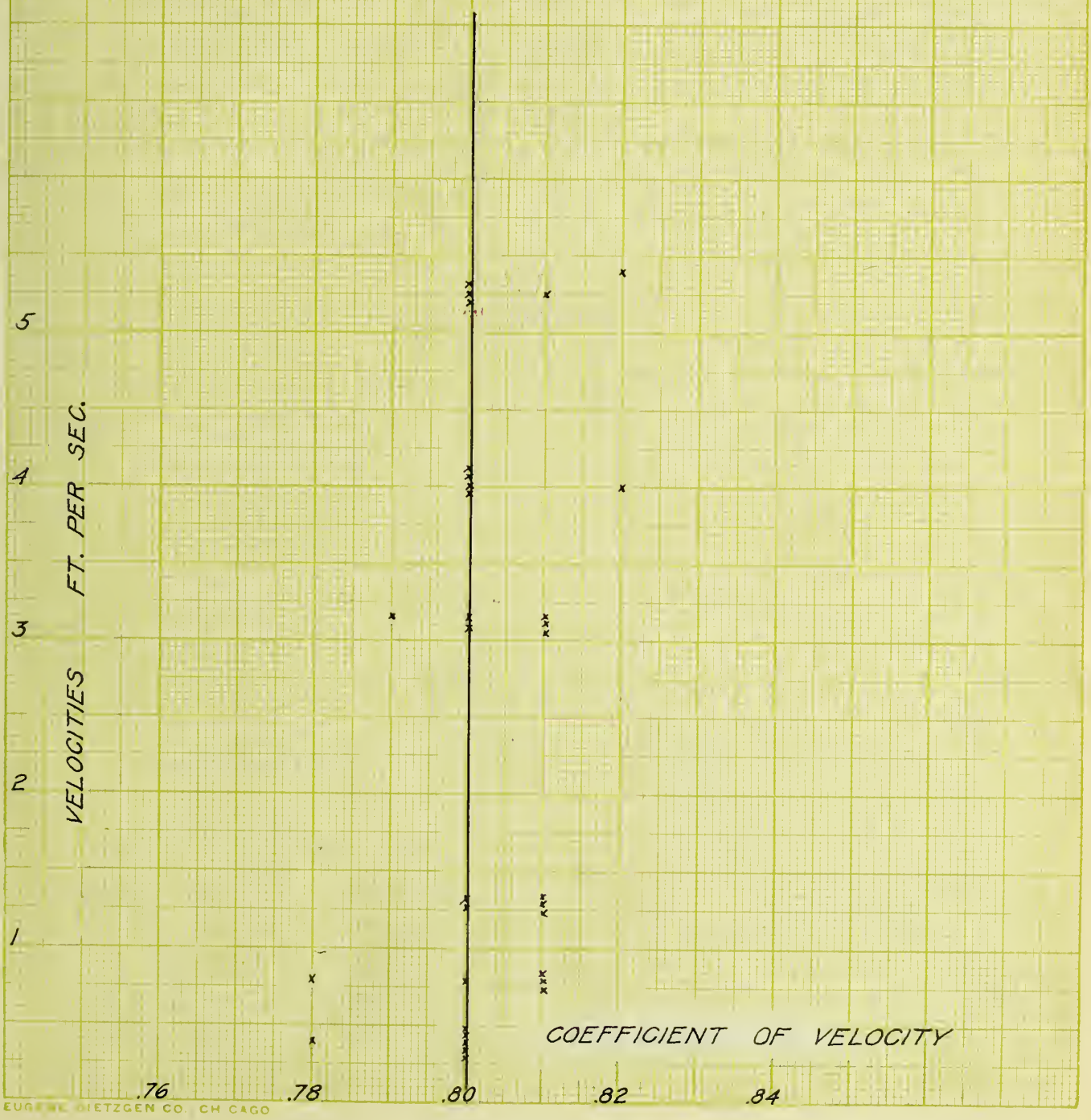
CURVE OF

VELOCITIES & COEFFICIENTS



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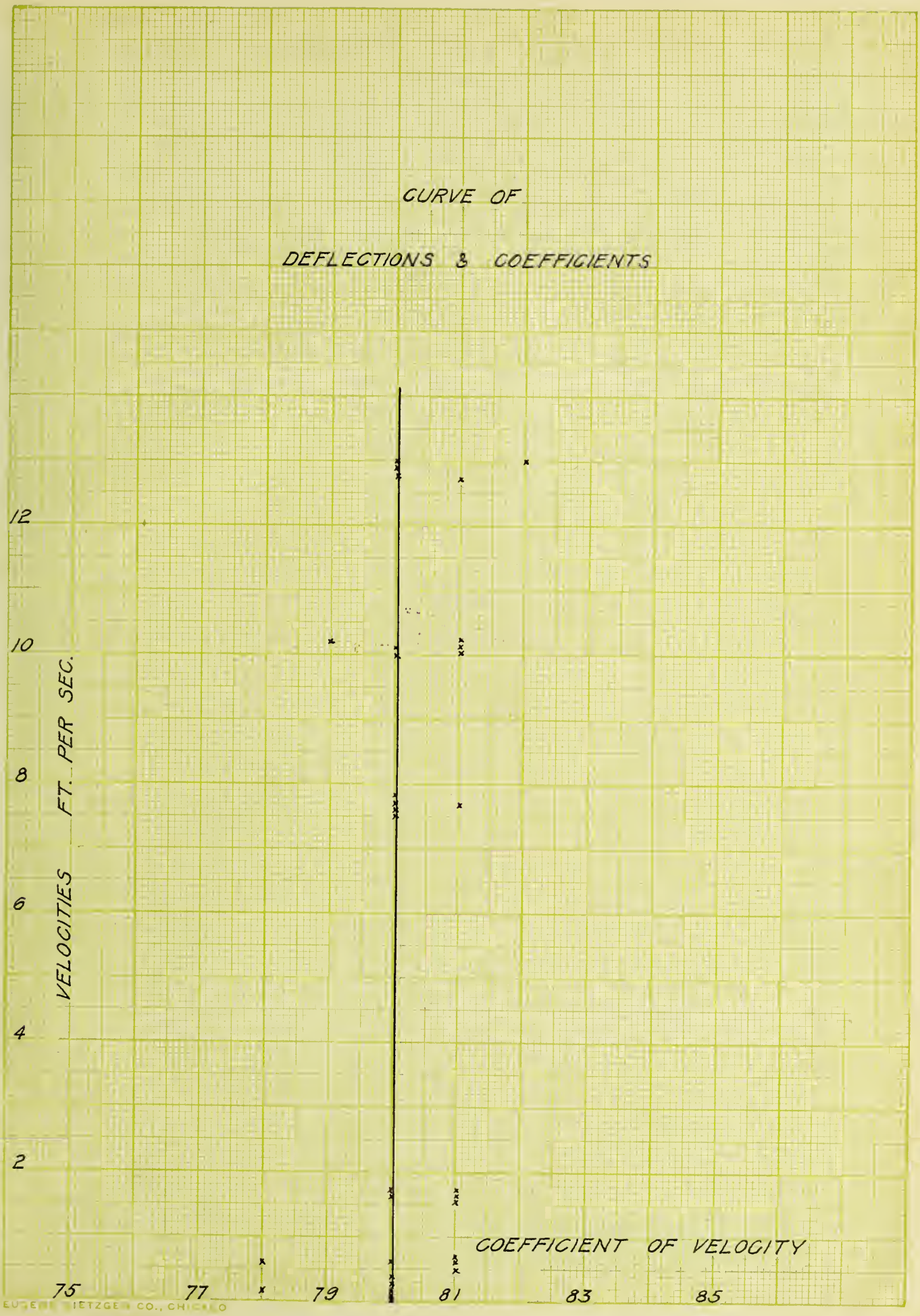
CURVE OF
DEFLECTIONS & COEFFICIENTS
VELOCITIES FT. PER SEC.
12
10
8
6
4
2
COEFFICIENT OF VELOCITY
75
77
79
81
83
85

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